Simulation-based parameterization of O^+ outfluxes produced by wave-driven ion heating and soft electron precipitation

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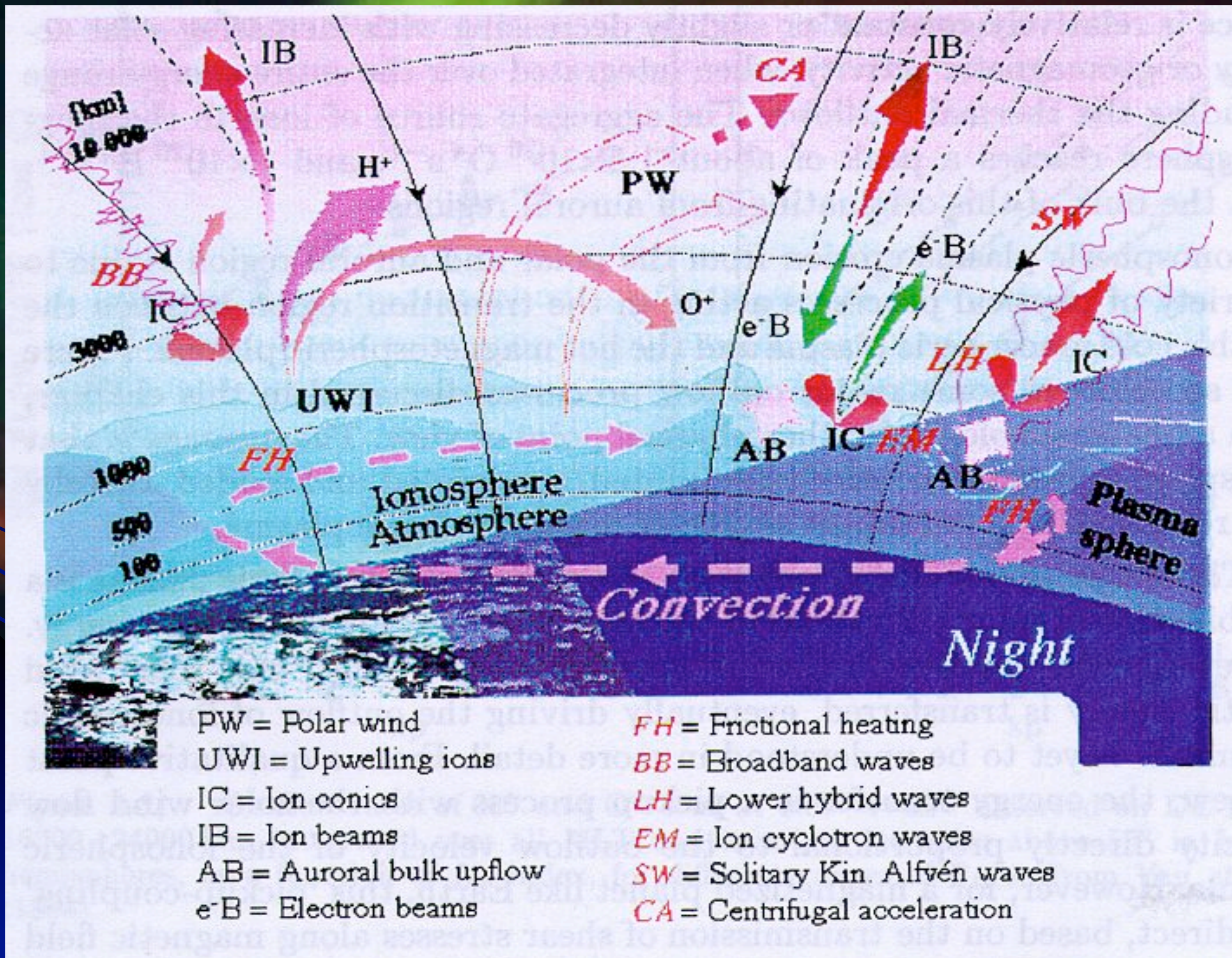
High-latitude Ionosphere



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Dynamic Fluid-Kinetic (DyFK) Model

- Treats ion distribution functions with collisional and kinetic features, includes self-consistent coupling to ionosphere.
- Time-dependent, 1.5-dimensional high-latitude plasma transport model.
- Couples truncated version of the Field Line Interhemisphere Plasma (FLIP) model to Generalized SemiKinetic (GSK) for higher altitudes.

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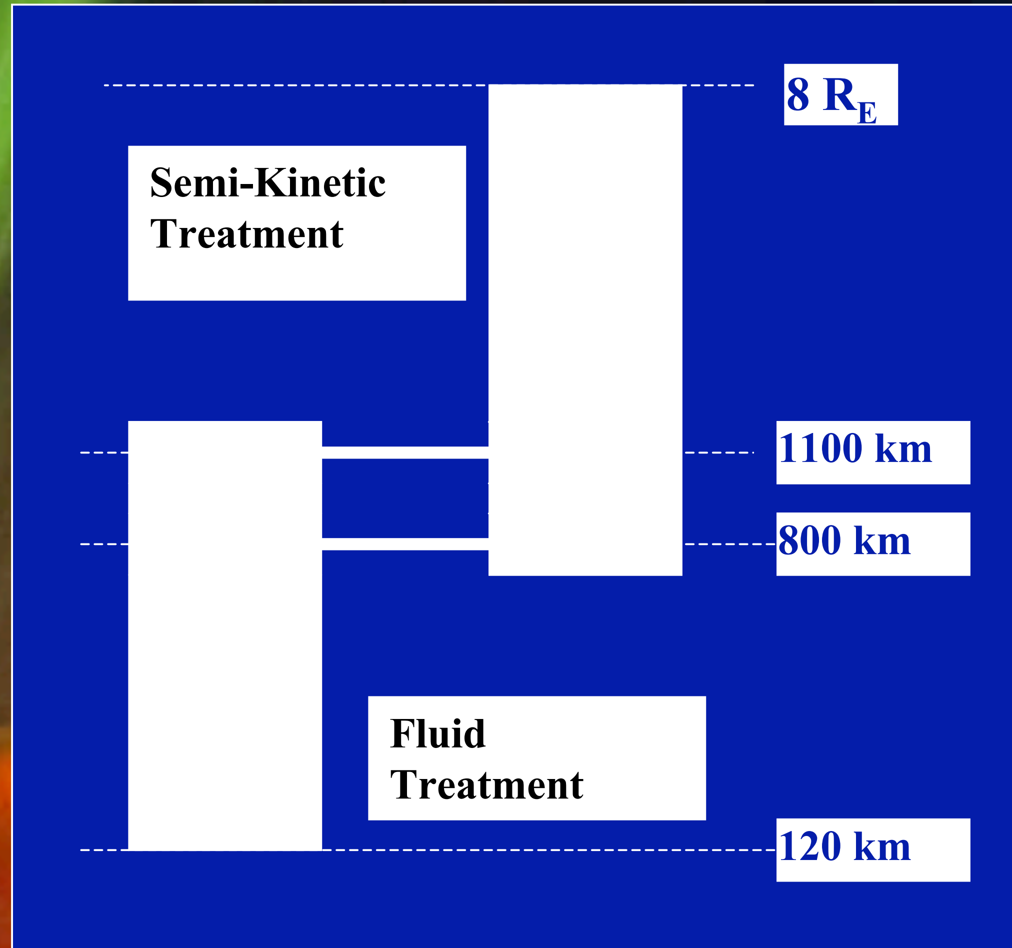
- Flux tube extends from 120 km to several R_E altitude.
- Fluid-region upper boundary conditions for successive steps from advancing GSK treatment.
- Lower boundary of GSK treatment set at 800 km altitude. Simulation H^+ and O^+ ions injected at lower boundary of GSK based on fluid-treatment results there.



The dynamic boundary coupling in an overlap region between the fluid and generalized semi-kinetic treatments in the DyFK model [after Estep et al., 1999]

Strangeway et al.[2005] analysis of FAST particle and field observations at 4000 km altitude:

Ion flux correlated with electron precipitation:

$$f_i = 1.022 \times 10^{9\pm0.341}\ n_{ep}^{2.200\pm0.489}$$

where f_i is the ion flux in $cm^{-2}s^{-1}$ and n_{ep} is precipitating electron density.

Correlation with Poynting flux:

$$f_i = 2.142 \times 10^{7\pm0.242}\ S^{1.265\pm0.445}$$

where S is the Poynting flux at 4000 km altitude in $mW\text{-}m^{-2}$.

Somewhat similar analysis by Zheng et al.[2005] with POLAR observations near 6000 km altitude.

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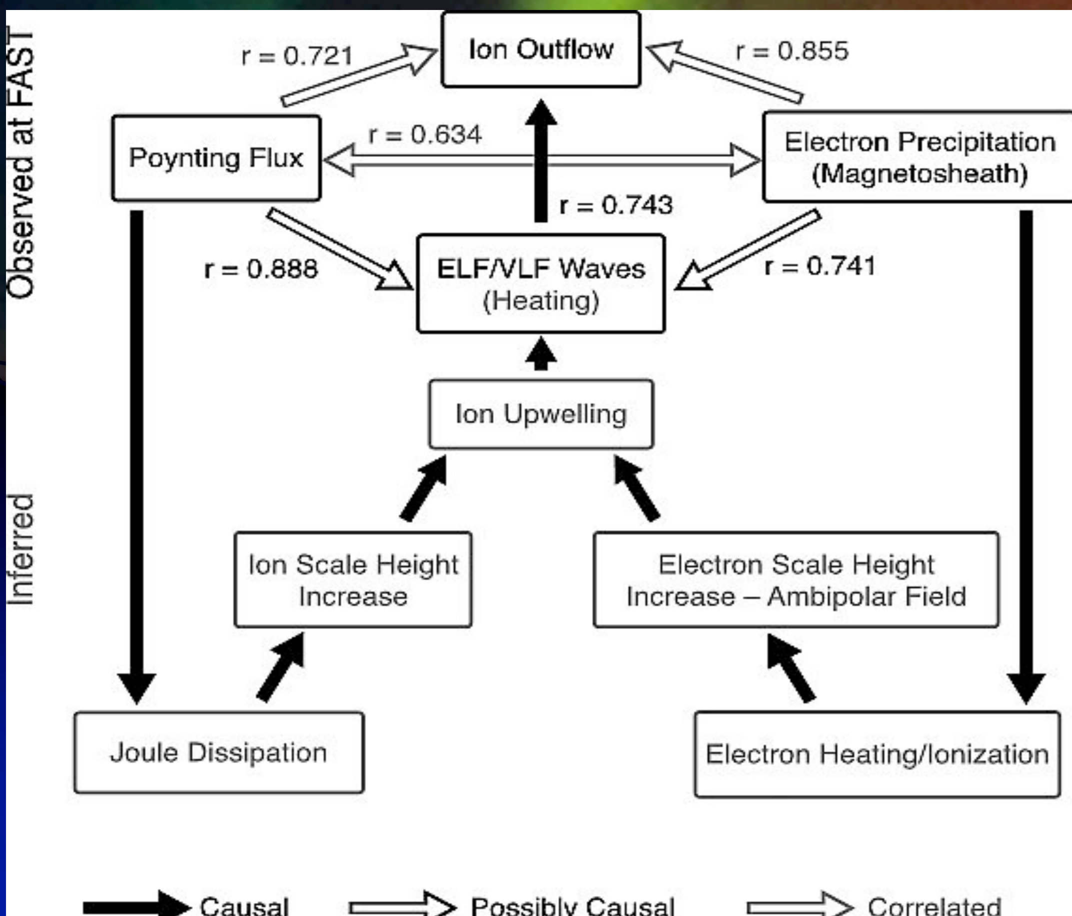
Toward a Formula Representation of the Effects of Wave-Particle Interactions and Soft Electron Precipitation on Ionospheric Outflows: Strangeway et al.[2005] Flow Diagram



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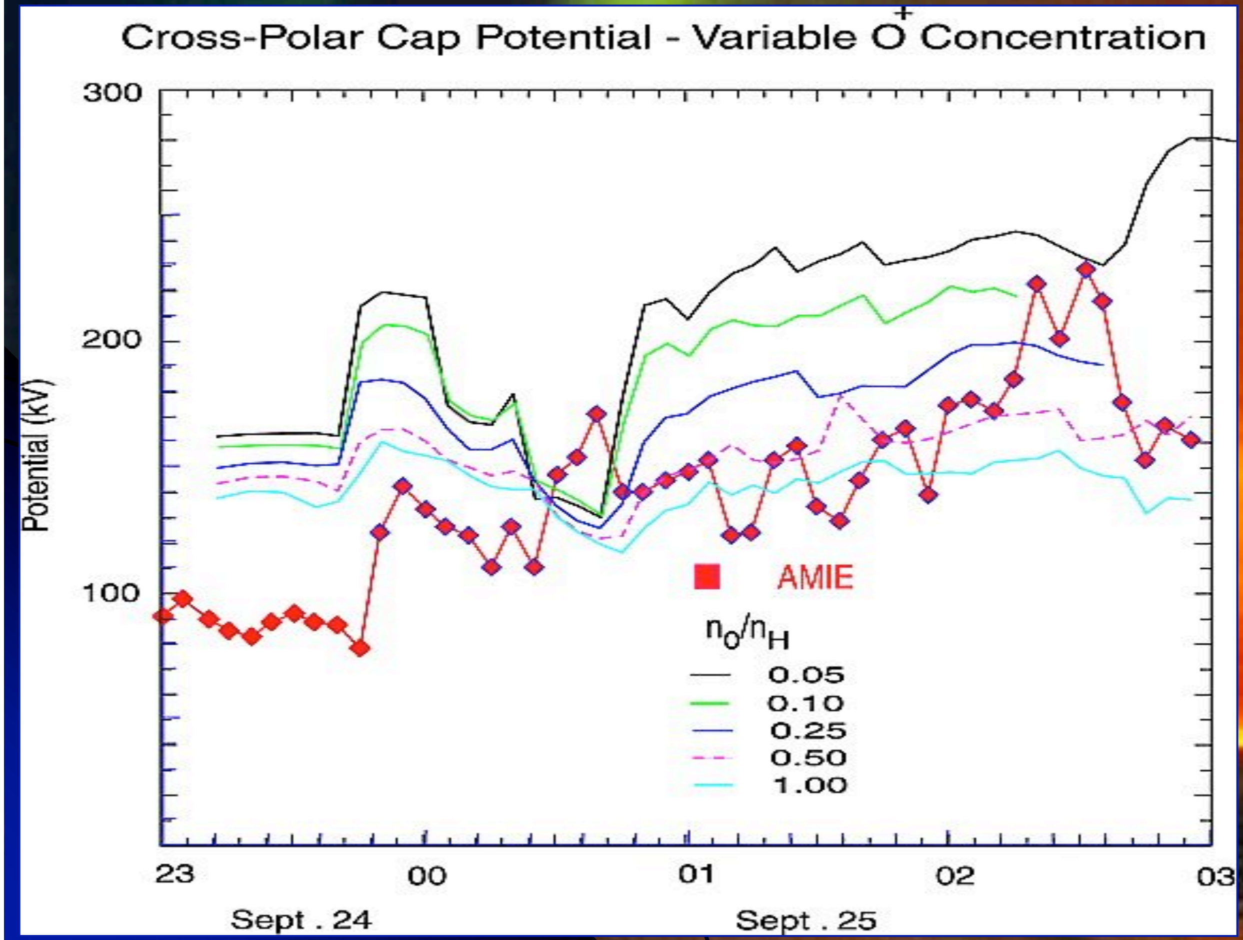
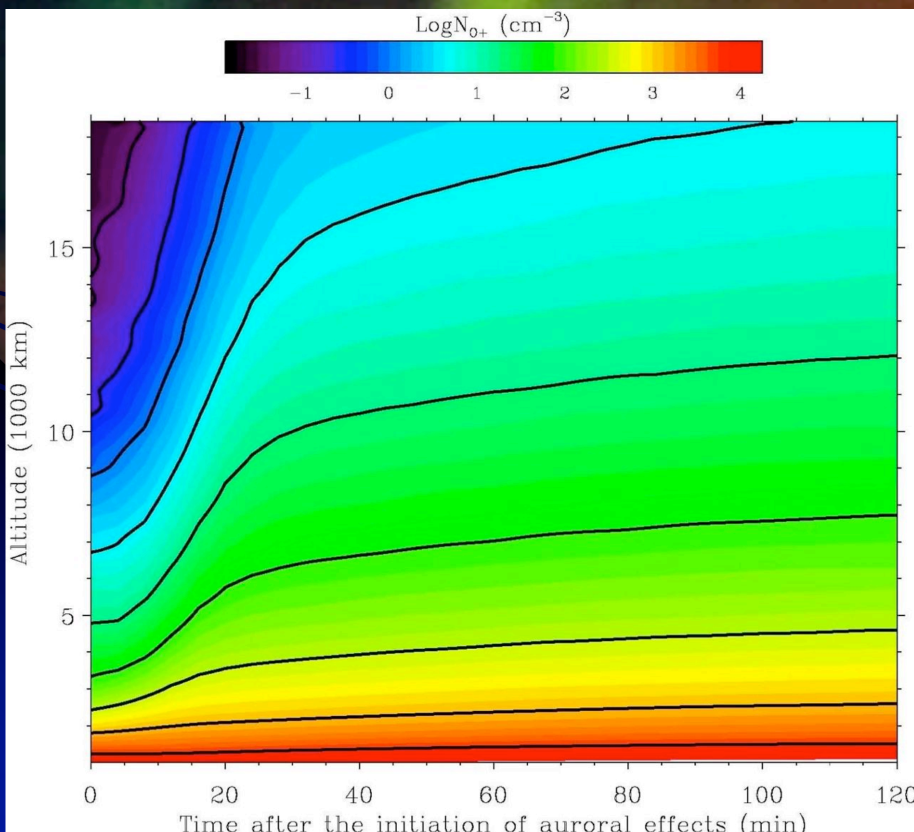
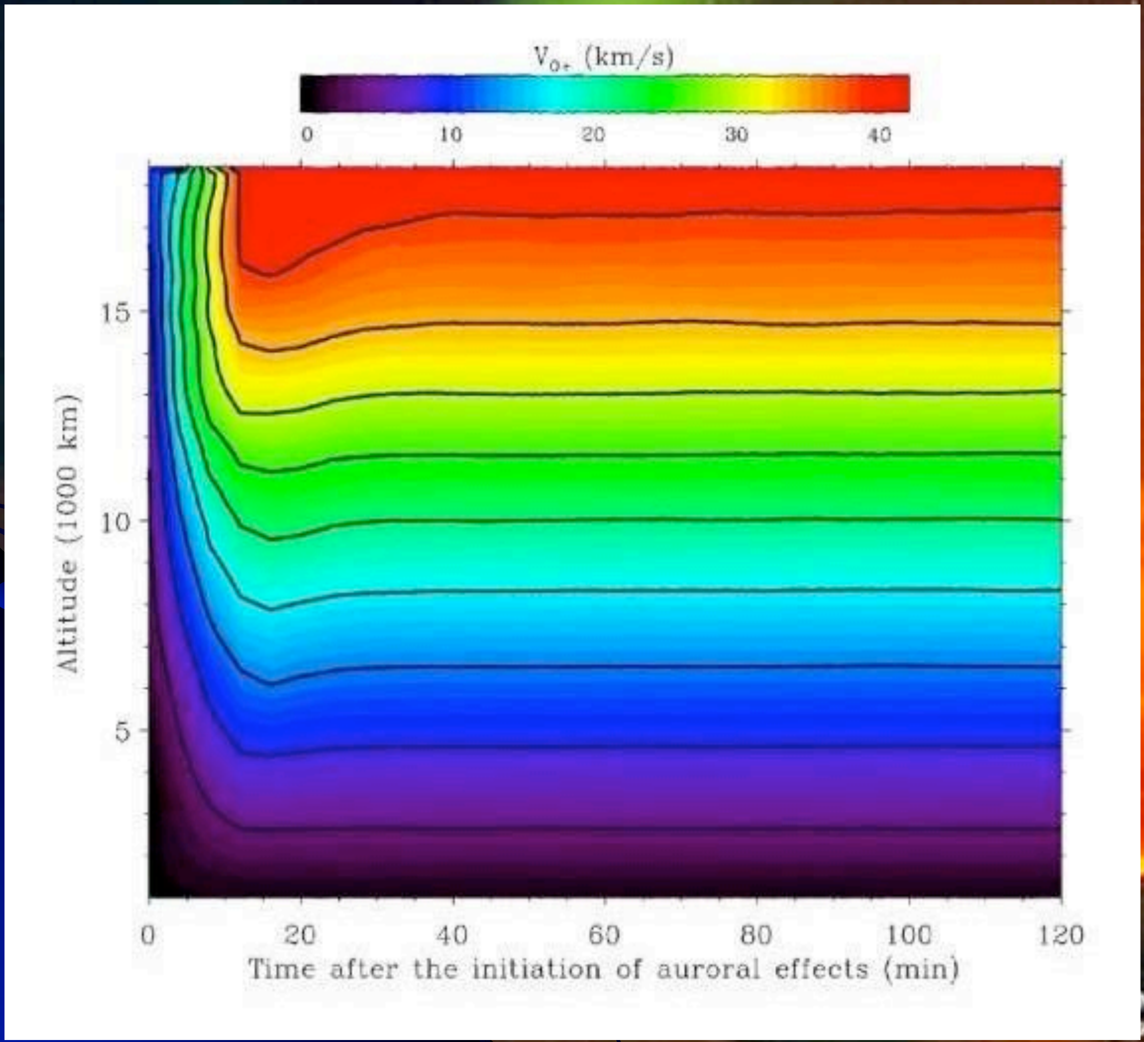
Winglee et al.[JGR, 2002]: Global impact of ionospheric outflows on the dynamics of the magnetosphere and cross-polar cap potential



To obtain a similar formula representation based on DyFK simulations, 140 DyFK runs were used to obtain the O^+ outflux at 3 R_E altitude in a flux tube (as then mapped to 1000 km altitude) subjected to the two indicated auroral processes for two hours. The evolution of the O^+ density for a typical run is displayed here.



Evolution of the O^+ field-aligned velocity profile for the same DyFK simulation run.



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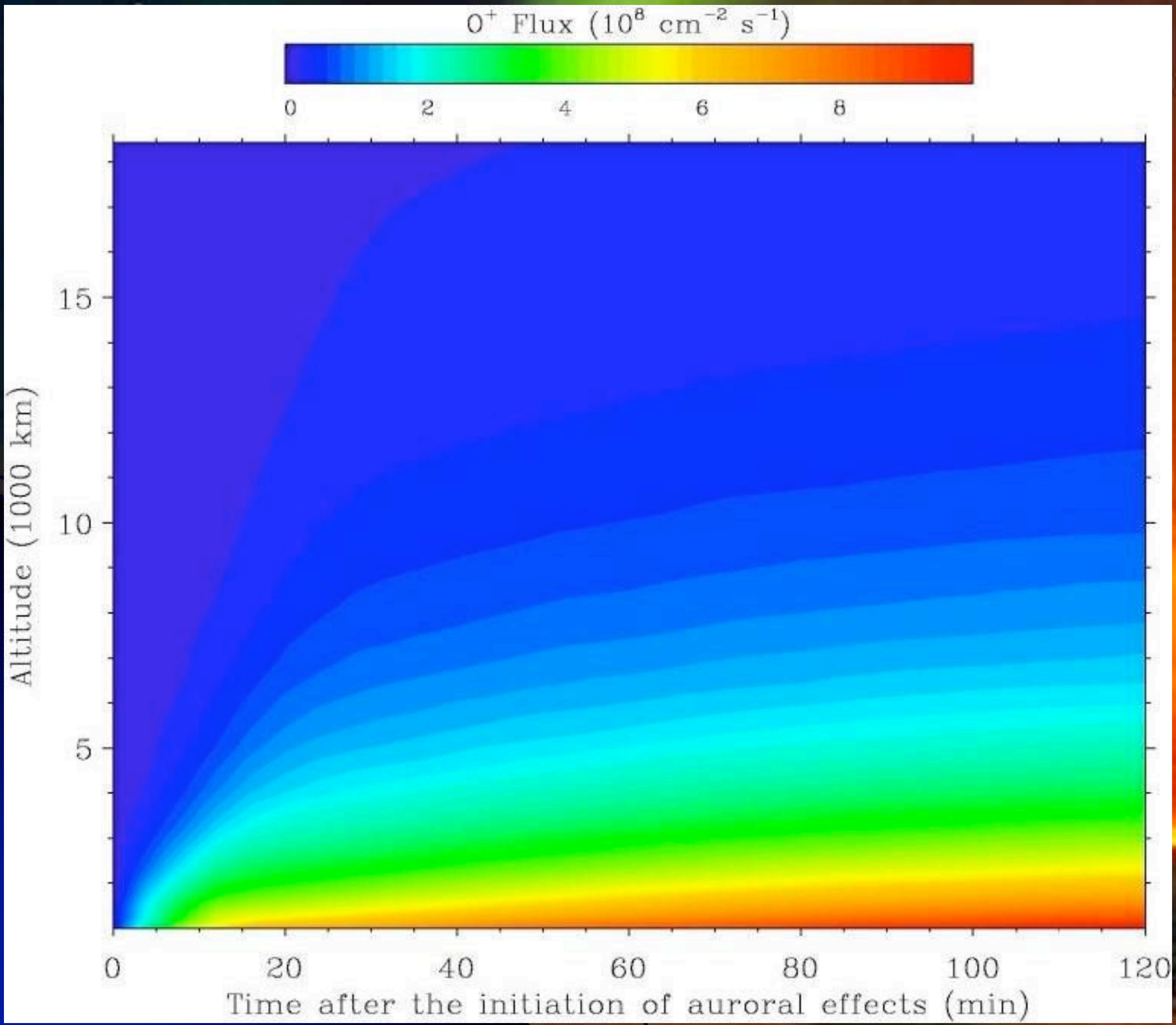
Evolution of the O^+ field-aligned flux profile for the same DyFK simulation run.



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O^+ Outflows versus Wave Spectral Level and Electron Precipitation for 140 DyFK Runs

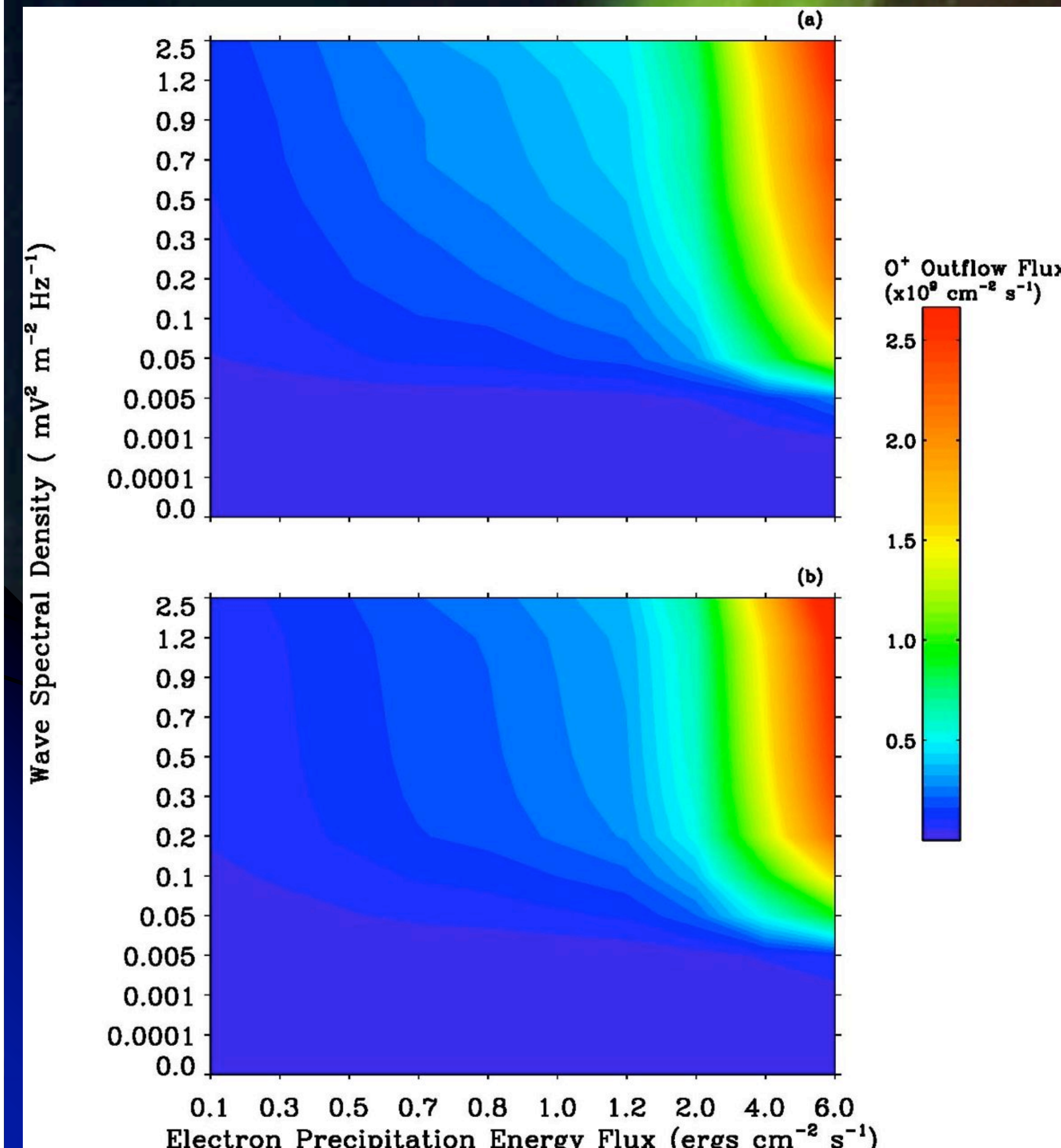

Figure (a-top) is the spectrogram of the O+ outflows from the DyFK simulations, while (b-bottom) is the spectrogram representing the formula:

$$Flux_{O^+} = 8.8(3.0\times10^5 + 0.02 f_e^{1.4}\times10^9)(\tanh(8D_{wave}) + 0.2D_{wave}^{0.6})$$

where $Flux_{O+}$ is the O^+ number flux in $cm^{-2}\ s^{-1}$ at 3 R_E mapped to 1000 km altitude; f_e is the electron precipitation energy flux in ergs $cm^{-2}\ s^{-1}$, and D_{wave} is the wave spectral density at 6.5 Hz in $(mV)^2\ m^{-2}\ Hz^{-1}$.

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Summary of Results for Formula Representation

Wave heating functions as “valve” for O^+.

When wave spectral density exceeds threshold, causes energization of majority of the entering O^+ ions to escape energies,

Further increases of wave spectral density cause no significant further increase in O^+ (number) outflux.

Electron precipitation causes ~ monotonic increases of O^+ outflux.

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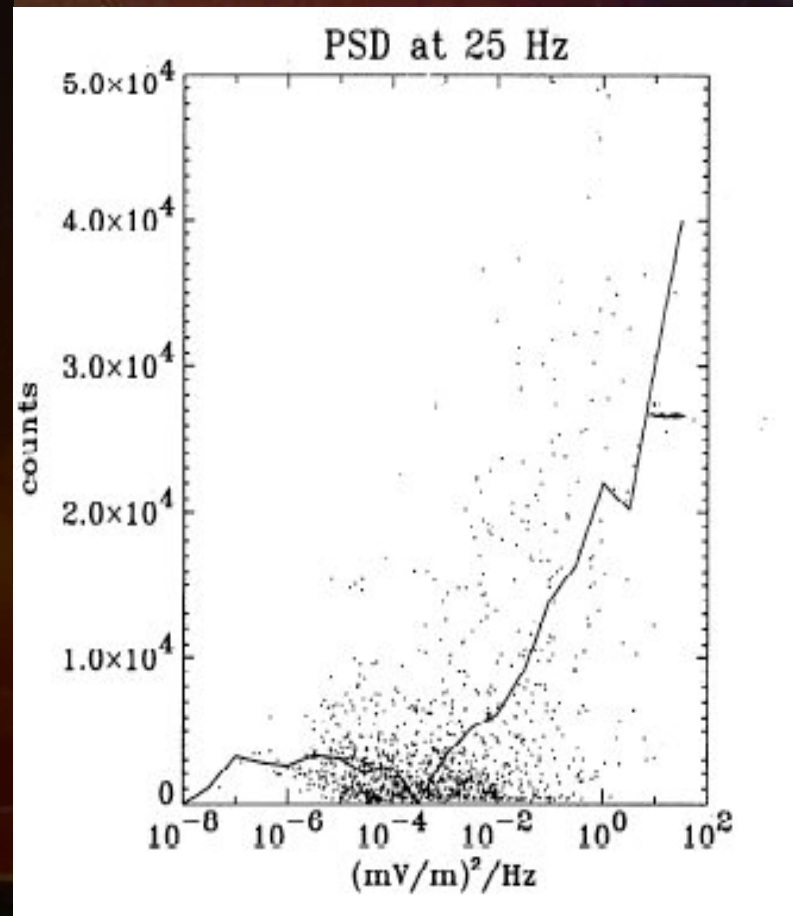
Observational evidence for wave-heating "valve" effect?

Knudsen et al[1998] examined Freja measurements, at ~1700 km altitude, for correlations between ion energization and electron bursts and BBELF waves. The plot at the right displays integrated 0-20 eV ion counts versus wave spectral density which suggest that significant local heating occurs only above a critical wave spectral density level. This is, however, somewhat different than the "valve" question of attainment of significant escape fluxes of O^+ requiring such a threshold in wave power.



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Future Directions for the Modeling of Ionospheric Outflows

- For this presentation on representing the O^+ outflows, the characteristic energy of the electron precipitation was fixed while the outfluxes were characterized vs. precipitation energy flux and the benchmark electric field wave spectral density value.
- We will also be investigating the additional dependences on such factors as the characteristic energy of the electron precipitation and the solar zenith angle in the F-region of the flux tubes.

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Preliminary Results on O^+ Outflux vs. Characteristic Precipitation Electron Energy

For the plot displayed, the precipitation electron energy flux was fixed at 1.0 ergs cm^{-2} s^{-1}, and wave spectral density at 0.3 mV^2 m^{-2} Hz^{-1} , as the characteristic energy of the electron precipitation was varied. The associated curve is:

$$Flux_{O^+} = 1.07\times10^8\, e^{\left(\frac{500-E_n}{390}\right)^{2.6}}$$

where E_n is the characteristic electron precipitation energy in eV.